a RANGEFINDER ~~AND IMAGER~~ for obtaining information from a three-dimensional object

BACKGROUND OF THE INVENTION

The present invention relates to a rangefinder for obtaining information about the three-dimensional (3D) location of an object and also relates to an imager.

Figure **22** illustrates an exemplary configuration for a prior art rangefinder. As shown in Figure **22**, a light source section **10** includes first and second light sources **11A** and **11B**. Filters **12A** and **12B** are disposed in front of the light-emitting ends of the light sources **11A** and **11B**, respectively. The light beams that have been emitted from the first and second light sources **11A** and **11B** are combined into a single beam at a half mirror **13**. Then, the combined beam is projected onto an object **1** after having passed through a slit **14** and a rotating mirror **15**. The output wavelengths of the light sources **11A** and **11B** are defined within the infrared range of the spectrum.

Figures **23(a)** and **23(b)** illustrate exemplary characteristics of the filters **12A** and **12B**. As shown in Figure **23(a)**, the filters **12A** and **12B** may selectively transmit light beams with mutually different wavelengths. Alternatively, these filters **12A** and **12B** may separate the light in accordance with the wavelength.

A camera section **20** includes first and second imagers

22A and **22B** for measuring the distance of the object **1**. In front of the light-receiving ends of these imagers **22A** and **22B**, disposed are filters **23A** and **23B**, which exhibit the same characteristics as the filters **12A** and **12B** in the light source section **10**, respectively. By using these filters **23A** and **23B**, the imagers **22A** and **22B** can separately receive respective parts of the light beams that have been emitted from the first and second light sources **11A** and **11B** and then reflected from the object **1**. The camera section **20** further includes a third imager **22C** for receiving light in the visible range of the spectrum. The output signal of the imager **22C** is processed by a color signal processor **27**, thereby obtaining a texture image (or color image) of the object **1**.

Figure **24(a)** illustrates a relationship between the intensity of the projected light beams and the projection angle θ of the combined light beam. As shown in Figure **24(a)**, a light source controller **16** controls the intensities **IA** and **IB** of the light beams emitted from the light sources **11A** and **11B**, respectively, as the projection angle θ of the combined light beam is changed by the rotating mirror **15**. Consequently, the intensity ratio **IA/IB** changes as shown in Figure **24(b)**. As can be seen from Figure **24(b)**, there is one-to-one correspondence between the intensity ratio **IA/IB** and the projection angle θ. That is to say, if the intensity ratio **IA/IB** is known, then the associated projection angle θ is

identifiable immediately. In addition, once the projection angle θ has been identified, the distance **Z** to the object **1** can be obtained as shown in Figure **24(c)**.

Hereinafter, it will be described how the prior art rangefinder shown in Figure **22** operates.

First, in the light source section **10**, the first and second light sources **11A** and **11B** output respective light beams. These outgoing light beams pass through the filters **12A** and **12B**, respectively, and then combined into a single beam at the half mirror **13**. Next, the combined light beam is transformed into vertically elongated slit-like light beam at the slit **14**. Then, the slit-like light beam is reflected from the rotating mirror **15**, which is controlled by a rotation controller **17**, so as to be projected onto the object **1**.

The reflected part of the light beam incident on the object **1** enters the camera section **20**. The respective imagers **22A**, **22B** and **22C** receive the reflected light beam via a lens **21** and half mirrors **24A** and **24B**. In this case, the combined light beam is separated by the filters **23A** and **23B** into respective beams, which are subsequently incident on the first and second imagers **22A** and **22B**. Each of these beams separated has a single corresponding wavelength.

A first light source signal processor **25** receives the output of the first imager **22A** and outputs a video signal corresponding to the reflected part of the light beam that

was initially emitted from the first light source **11A**. In the same way, a second light source signal processor **26** receives the output of the second imager **22B** and outputs a video signal corresponding to the reflected part of the light beam that originated from the second light source **11B**. Responsive to the video signals provided from the first and second light source signal processors **25** and **26**, a range calculator **30** calculates the intensity ratio on a pixel-by-pixel basis, and then estimates the projection angle θ for each pixel based on the correspondence shown in Figure **24(b)**.

In this case, a viewing angle ϕ is defined for each pixel location at the imager as an angle formed between a line of sight passing through the center of the lens **21** and the optical axis of the lens **21** as shown in Figure **22**. There is also one-to-one correspondence between each pixel location and the associated viewing angle ϕ. Thus, if a particular pixel location is given, then the associated viewing angle ϕ is known automatically. In addition, the distance **D** between the center of the lens **21** and the center of rotation of the rotating mirror **15** is also already known as shown in Figure **22**.

Thus, the range calculator **30** can obtain, by the triangulation technique, the distance **Z** between a point on the object **1**, which corresponds to each pixel location, and the camera section **20** on a pixel-by-pixel basis by substituting

the projection angle θ, viewing angle ϕ and distance **D** into the following Equation (1):

$$Z=(\tan\theta \cdot \tan\phi / \tan\theta - \tan\phi) \cdot D \qquad (1)$$

In this manner, information about the 3D location of the object **1** can be obtained.

Also, not just the information about the 3D location of the object **1**, but the texture image (or color image) of the object **1** are obtainable from the color signal processor **27** based on the output of the third imager **22C**.

The prior art rangefinder, however, has the following drawbacks.

Firstly, in the conventional rangefinder, the optical output power of the light source section **10** is supposed to be adjusted by the user. In fact, the power has been adjusted appropriately through the user's experience or by his or her trial and error. In other words, if a beginner should handle such a rangefinder, it is usually difficult for him or her to control the optical output power effectively. As a result, the user cannot always obtain precise range information. Secondly, if the object is on the move, then the optical output power should be re-adjusted for every movement of the object, thus taking too much time and trouble. Thirdly, supposing the output power is set too high while the object is located very close to the rangefinder, some harm might be done on the object.

Moreover, the known rangefinder has additional problems. Figure **25** illustrates the signal levels of a video signal during a 3D imaging process. In Figure **25**, **L** represents the signal level of the overall video signal, **LA** represents the signal level of reflected part of the light and **LB** represents the signal level of an image component of an object (i.e., background light). To increase the precision of the 3D location information, the optical output power of the light source section **10** should be set at such a value as increasing the signal-to-noise ratio of the signal level **LA** of the reflected light component. However, since the dynamic range of the camera section **20** is predefined, the signal level **LA** of the reflected light component cannot be increased above a certain maximum acceptable level. On the other hand, the signal level **LB** of the image component of the object should be no lower than a certain minimum acceptable level to obtain a normal two-dimensional (2D) image. Accordingly, the signal-to-noise ratio of the object cannot be increased sufficiently, thus interfering with the precision improvement of the 3D location information.

Furthermore, in the field of computer vision, for example, a technique of dividing the image of an object into foreground and background parts based on the range information about the object and then separating only the foreground part is known. However, a system like a videophone is strongly re-

quired to separate a human face image (i.e., the foreground part of the image) from the background accurately, but it is not always necessary for such a system to obtain the range information itself about the object. Accordingly, a technique of dividing the image of an object into foreground and background parts without using the range information thereof should preferably be developed.

SUMMARY OF THE INVENTION

An objective of the present invention is providing a rangefinder that can always obtain highly precise information about the 3D location of an object without doing any harm on the object.

Another objective of the present invention is providing an imager that can divide the image of an object into foreground and background parts without using the range information about the object.

Specifically, a rangefinder according to the present invention is adapted to obtain information about the 3D location of an object by projecting light onto the object and receiving part of the light that has been reflected from the object. The rangefinder includes: a light source for projecting the light on the object; a camera for receiving the part of the projected light that has been reflected from the object; and a controller for controlling optical output power

of the light source and/or exposure conditions of the camera based on range information about the object.

According to the present invention, the optical output power of the light source and/or the exposure conditions of the camera are controlled based on the range information about the object. That is to say, even if the object has moved, the intensity of the projected light and/or the signal level of the received light is/are controlled correspondingly. As a result, highly precise 3D location information can always be obtained. Also, the inventive rangefinder is operative such that the projected light does no harm on even an object that has come too close to the rangefinder.

In one embodiment of the present invention, the rangefinder may further include a distance-measuring sensor for measuring the distance to the object, and the controller may use the output of the distance-measuring sensor as an item of the range information about the object.

In an alternate embodiment, the rangefinder may further include a range calculator for obtaining a range image based a video signal output from the camera, and the controller may use the range image obtained by the range calculator as an item of the range information about the object.

In another embodiment of the present invention, if the controller has determined based on the range information that the distance to the object is equal to or greater than a first

threshold value, then the controller preferably increases the optical output power of the light source. Alternatively, if the controller has determined based on the range information that the distance is equal to or smaller than a second threshold value, then the controller preferably decreases the optical output power of the light source.

In still another embodiment, the exposure conditions of the camera are preferably defined based on at least one of a diaphragm stop, a sensitivity of an imager and a shutter speed.

In yet another embodiment, the rangefinder may further include a shutter, which can open and close freely and blocks the light that has been projected from the light source when closed, and the controller preferably controls the open and closed states of the shutter selectively.

Another rangefinder according to the present invention is also adapted to obtain information about the 3D location of an object by projecting light onto the object and receiving part of the light that has been reflected from the object. The rangefinder includes: a light source for projecting the light on the object; a camera for receiving the part of the projected light that has been reflected from the object; and a controller for controlling optical output power of the light source and/or exposure conditions of the camera based on information about the level of a video signal output from the

camera.

According to the present invention, the optical output power of the light source and/or the exposure conditions of the camera are controlled based on information about the level of a video signal output from the camera. That is to say, even if the object has moved, the intensity of the projected light and/or the signal level of the received light is/are controlled correspondingly. As a result, highly precise 3D location information can always be obtained.

In one embodiment of the present invention, if the controller has determined based on the level information that the distance to the object is equal to or greater than a first threshold value, the controller preferably increases the optical output power of the light source. Alternatively, if the controller has determined based on the level information that the distance is equal to or smaller than a second threshold value, the controller preferably decreases the optical output power of the light source.

In another embodiment of the present invention, the exposure conditions of the camera are preferably defined based on at least one of a diaphragm stop, a sensitivity of an imager and a shutter speed.

In still another embodiment, the rangefinder may further include a shutter, which can open and close freely and blocks the light that has been projected from the light source when

closed, and the controller preferably controls the open and closed states of the shutter selectively.

Still another rangefinder according to the present invention is also adapted to obtain information about the 3D location of an object by projecting light onto the object and receiving part of the light that has been reflected from the object. The rangefinder includes: a light source for projecting the light on the object; a camera for receiving the part of the projected light that has been reflected from the object, the camera being able to capture a 2D image; and a controller for setting a signal level of an image component of the object lower in capturing a three-dimensional image than in capturing the 2D image so as to sufficiently increase a signal level of the reflected light when the light source projects the light on the object.

According to the present invention, the image component of the object has its signal level lowered in capturing a 3D image compared to capturing a 2D image. As a result, the signal-to-noise ratio of the signal representing that part of the projected light reflected from the object increases and yet the quality of the 2D image does not deteriorate. Thus, the precision of the 3D location information improves.

In one embodiment of the present invention, the camera may include a filter for adjusting an intensity per unit area of the light incident on the camera. And the controller may

set transmittance of the filter relatively low in capturing the 3D image and relatively high in capturing the 2D image.

In this particular embodiment, the filter preferably includes a liquid crystal device. The transmittance of the filter is preferably controllable based on a voltage applied to the liquid crystal device.

In an alternate embodiment, the controller may control the exposure conditions of the camera.

In this particular embodiment, the exposure conditions of the camera are preferably defined based on at least one of a diaphragm stop, a sensitivity of an imager and a shutter speed.

An imager according to the present invention includes: a light source for projecting light onto an object, the optical properties of the projected light changing depending on a direction in which the light has been projected; a camera for capturing a 2D image of the object by receiving part of the projected light that has been reflected from the object; and a foreground/background distinguisher for dividing the 2D image into foreground and background parts based on optical properties of the light that has been reflected from the object.

According to the present invention, a 2D image is divided into foreground and background parts based on the optical properties of the light that was emitted from a light source

toward an object and then reflected from the object. Thus, the image is separable into the foreground and background parts without using the range information.

In one embodiment of the present invention, the imager may further include a separator for cutting out the foreground or background part from the 2D image based on the result of division performed by the identifier.

In another embodiment of the present invention, the light source may project first and second light beams. The intensity of each of the first and second beams is variable depending on a direction in which the beam has been projected. The intensity of the first beam changes in a different pattern than that of the second beam. And the foreground/background distinguisher may distinguish the foreground and background parts from each other based on an intensity ratio of reflected part of the first beam to that of the second beam.

In an alternate embodiment, the light source may project light with an intensity variable depending on a direction in which the light has been projected. And the foreground/background distinguisher may distinguish the foreground and background parts from each other based on an intensity of reflected part of the projected light.

In still another embodiment, the imager may further include a threshold determiner for determining a threshold value on an object-by-object basis as a reference for distinguishing

the foreground and background parts from each other.

In this particular embodiment, the threshold determiner preferably determines the threshold value based on the distribution of optical properties of the light that has been reflected from the object and incident on respective pixels in the camera.

In an alternate embodiment, the threshold determiner may determine the threshold value based on a surface reflectance of the object.

In this particular embodiment, the imager preferably further includes a distance-measuring sensor for measuring the distance to the object, and the threshold determiner preferably estimates the surface reflectance of the object based on the distance measured by the distance-measuring sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure **1** is a block diagram illustrating a configuration for a rangefinder according to a first embodiment of the present invention.

Figures **2(a)** and **2(b)** illustrate the operating principle of the rangefinder shown in Figure **1**:

Figure **2(a)** is a graph showing a relationship between the distance to an object and the optical output power of a light source section; and

Figure **2(b)** is a graph showing a relationship between the distance to the object and the open/closed states of a shutter.

Figures **3(a)** and **3(b)** illustrate another exemplary arrangement of the light source section.

Figure **4** illustrates an embodiment where the exposure conditions of a camera section are controlled based on a shutter speed.

Figure **5** is a block diagram illustrating a configuration for a rangefinder according to a second embodiment of the present invention.

Figure **6** illustrates a relationship between the operation of the rangefinder shown in Figure **5** and the transmittance of an ND filter.

Figure **7** is a graph illustrating a relationship between the sensitivity of a CCD included in the camera section of the rangefinder shown in Figure **5** and the wavelength of the incident light.

Figures **8(a)** and **8(b)** illustrate the primary technical feature of the second embodiment:

Figure **8(a)** illustrates the level of a video signal in a first interval **T1** for 3D imaging; and

Figure **8(b)** illustrates the level of the video signal in a second interval **T2** for 2D imaging.

Figure **9** illustrates another exemplary arrangement of

the light source and camera sections in the rangefinder.

Figure **10** illustrates how to time the projection of two types of light patterns on a time sharing basis.

Figure **11** is a block diagram illustrating a configuration for a videophone system including an imager according to a third embodiment of the present invention.

Figure **12(a)** illustrates how the system shown in Figure **11** operates; and

Figure **12(b)** illustrates two types of intensity patterns.

Figures **13(a)** through **13(d)** illustrate how to distinguish foreground and background parts from each other based on an intensity ratio.

Figures **14(a)** and **14(b)** illustrate a situation where the foreground/background division criterion shows hysteresis.

Figures **15(a)** and **15(b)** illustrate how to distinguish the foreground and background parts from each other based on the intensity itself.

Figure **16** is a block diagram illustrating a configuration for a videophone system including an imager with a threshold determiner according to a first modified example of the third embodiment.

Figure **17(a)** illustrates how to determine a threshold value by a mode method; and

Figure **17(b)** illustrates how to determine a threshold

value by a P-tile method.

Figure **18** is a block diagram illustrating a configuration for a videophone system including an imager with a distance-measuring sensor and a threshold determiner according to a second modified example of the third embodiment.

Figure **19** illustrates another exemplary arrangement of the light source section.

Figure **20** illustrates an exemplary technique of changing a threshold value depending on a pixel location.

Figure **21** illustrates another exemplary technique of changing a threshold value depending on a pixel location.

Figure **22** is a block diagram illustrating a configuration for a prior art rangefinder.

Figures **23(a)** and **23(b)** illustrate the optical characteristics of filters included in the rangefinder shown in Figure **22**.

Figure **24(a)** is a graph illustrating a relationship between the intensities of light beams emitted and the projection angle of a combined light beam;

Figure **24(b)** is a graph illustrating a relationship between the intensity ratio of the light beams emitted and the projection angle of the combined light beam; and

Figure **24(c)** is a graph illustrating a relationship between the projection angle and the distance to the object.

Figure **25** illustrates the level of a video signal where

the prior art rangefinder captures a 3D image.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings.

EMBODIMENT 1

Figure **1** illustrates a configuration for a rangefinder according to a first exemplary embodiment of the present invention. In Figure **1**, the same members as those included in the prior art rangefinder shown in Figure **22** are identified by the same reference numerals and the detailed description thereof will be omitted herein.

As shown in Figure **1**, the rangefinder includes a distance-measuring sensor **101** for estimating an approximate averaged distance from the rangefinder to an object **1**. The distance-measuring sensor **101** is implementable as a sensor of the type detecting ultrasonic waves reflected from the object **1**. The rangefinder also includes an exposure controller **102**, which is equivalent to the controller as defined in the appended claims. Based on range information provided from the distance-measuring sensor **101**, the exposure controller **102** controls the operations of a light source controller **16** and a shutter **104**. As in the known rangefinder, the light source controller **16** controls the optical output power (or the emis-

sion intensity per unit area) of a light source section **10**. The shutter **104** is disposed in a freely opening and closing position in front of the light projected from the light source section **10**. When closed following an instruction issued from the exposure controller **102**, the shutter **104** cuts off the optical path of the light projected from the light source section **10**.

Next, it will be described with reference to Figures **2(a)** and **2(b)** how the rangefinder shown in Figure **1** operates. Figure **2(a)** shows a relationship between the distance **L** to the object **1** and the optical output power of the light source section **10**, while Figure **2(b)** shows a relationship between the distance **L** to the object **1** and the open/closed states of the shutter **104**.

First, the distance-measuring sensor **101** measures the distance **L** to the object **1** and provides the result **L** to the exposure controller **102**. At this point in time, no light has not been projected from the light source section **10** yet. In response to the given distance **L**, the exposure controller **102** finds out the location of the object **1** based on predetermined first and second reference values **l1** and **l2**, i.e., in which of the first (very short), second (intermediate) and third (long) ranges the object **1** is now located. The location of the object **1** is determined as follows:

1) if $0 \leqq L \leqq l1$, then the object is located in the first

range;

2) if $l1 < L < l2$, then the object is located in the second range; and

3) if $l2 \leqq L$, then the object is located in the third range.

Depending on the location of the object **1**, the exposure controller **102** operates in the following manner:

1) If the object **1** is located in the first range, then the exposure controller **102** avoids the projection of light onto the object **1** because the object **1** is located too close to the rangefinder. Accordingly, the exposure controller **102** sets the optical output power of the light source section **10** relatively low as shown in Figure **2(a)**, and totally closes the shutter **104** as shown in Figure **2(b)**, thereby preventing the light from being projected onto the object **1**. It is noted, however, that the optical output power of the light source section **10** should not be turned OFF completely. This is because the optical output power of the light source section **10** can rise faster on demand compared to the situation where the power is turned OFF completely.

It is for the purpose of protecting the object **1** from the optical power radiated that the projection of the light onto the object **1** is avoided. Particularly when laser radiation is emitted from the light source section **10**, the energy applied to that too closely located object **1** will be of an

excessively high density, and therefore some harm might be done on the object **1**.

Since no light is projected on the object **1** in this case, no 3D location information is obtained. To collect the 3D location information, the object **1** should be moved to an appropriate location, which is moderately distant from the rangefinder.

2) If the object **1** is located in the second range, then

the exposure controller **102** opens the shutter **104** as shown in Figure **2(b)**, and controls the optical output power of the light source section **10** as shown in Figure **2(a)** such that the level of a video signal output from the camera section **20** falls within an appropriate range. In this manner, it is possible to prevent the intensity of the light projected per unit area from reaching too high or too low a level, thus always ensuring a high signal-to-noise ratio for the reflected part of the light projected. As a result, highly precise 3D location information can be obtained.

3) If the object **1** is located in the third range, then

the light source section **10** should project as intense light as possible because the object **1** is located too distant from the rangefinder. Thus, the exposure controller **102** opens the shutter **104** as shown in Figure **2(b)**, and sets the optical output power of the light source section **10** relatively high, or preferably maximizes the power, as shown in Figure **2(a)**.

If the object **1** is located in either the second or third range, then the 3D location information is obtained by the known technique after the operations specified in 2) and 3) have been performed.

In the illustrated embodiment, the optical output power of the light source section **10** is controlled with the distance to the object **1** divided into three ranges. It should be noted, however, that the optical output power is controllable by any other technique. For example, the first and second reference values **11** and **12** may be combined together, i.e., the optical output power is also controllable by two steps. Alternatively, the optical output power is controllable more finely by dividing the distance into a greater number of ranges.

The exposure conditions of the camera section **20** may be controlled instead of, or in addition to, the control over the optical output power of the light source section **10**. For that purpose, the diaphragm stop, sensitivity of the imager or shutter speed may be controlled, for example. Specifically, when the object **1** is located in the second range, the optical output power of the light source section **10** may be maximized (i.e., 100% power may be output), and the exposure conditions of the camera section **20** are adjustable such that the level of the video signal output from the camera section **20** falls within a proper range.

Optionally, just the optical output power of the light source section **10** and/or the exposure conditions of the camera section **20** may be controlled with the shutter **104** eliminated from the rangefinder.

Figure **3(a)** illustrates another exemplary configuration for the light source section **10**. As shown in Figure **3(a)**, variable transmittance filters **41A** and **41B** are disposed in front of the light sources **11A** and **11B**, respectively. That is to say, this light source section **10** is so constructed as to project patterned light beams, not to sweep the object **1** with the single combined beam. As shown in Figure **3(b)**, the transmittance of each of the variable transmittance filters **41A** and **41B** differs depending on the position through which the light is transmitted. When monochromatic light sources such as laser diodes are used as the light sources **11A** and **11B**, the filters **12A** and **12B** may be omitted.

Figure **4** illustrates an embodiment where the exposure conditions of the camera section **20** are controlled based on the shutter speed thereof. To control the exposure conditions in accordance with the shutter speed, the light source section **10** is supposed to project patterned light beams as shown in Figure **3**, not the sweeping type. In this case, the emission interval **T** of the light source section **10** should preferably be constant as shown in portion **(a)** of Figure **4**. Also, the exposure interval **T0** of the camera section **20** per

vertical interval should preferably be changed by controlling the shutter speed as shown in portion **(b)** of Figure **4**. Conversely, the exposure interval **T0** of the camera section **20** may be constant, and the emission interval **T** of the light source section **10** may be changed. In such a case, $T0 \geqq T$ is met.

In the foregoing embodiment, the distance-measuring sensor **101** is provided as exemplary means for obtaining range information about the object. It should be noted, however, that such means is an optional one, not indispensable. If the sensor **101** is omitted, then the optical output power of the light source section **10** and/or the exposure conditions of the camera section **20** are controllable by using a "range image" that has been obtained by the range calculator **30** as an item of the range information about the object **1**. Nevertheless, since the range information is needed first of all to identify the location of the object **1**, the light source section **10** should initially project the light onto the object **1** in such a case. However, the optical output power of the light source section **10** should preferably be minimized at first because the location of the object **1** is unknown at this stage.

In this specification, the "range image" means an image in which the distances from the camera or the depths in a three-dimensional coordinate system are specified for respective pixels. The distance from the camera corresponds to r

in a spherical coordinate system (r, θ, ϕ), while the depth corresponds to z in a rectangular coordinate system (x, y, z).

Also, the range image obtained by the range calculator **30** might be seriously erroneous if the level of the video signal output from the camera section **20** is inappropriate. For instance, supposing the object **1** is located too far, the signal-to-noise ratio of the range image is appreciably low because just a weak signal is obtained for the light reflected from such a far object **1**. If the power and/or exposure conditions are controlled using the range image with such a low signal-to-noise ratio as an item of the range information about the object, then the system might lose it stability. In other words, by providing additional sensing means such as the distance-measuring sensor **101** separately from the means for obtaining the range image and using the distance measured by that means as range information about the object as is done in the foregoing embodiment, more stabilized control is realized.

The optical output power of the light source section **10** and/or the exposure conditions of the camera section **20** are controllable based on the information about the level of the video signal output from the camera section **20**, instead of the range information about the object **1**.

In the foregoing embodiment, the present invention has

been described as being applied to a rangefinder for capturing a 3D image based on an intensity ratio. Alternatively, the rangefinder is operative based on any other optical characteristic such as the wavelength of the light. In such a case, the camera section **20** shown in Figure **1** should be replaced with a camera that can measure the wavelength of reflected light beam. Also, not just the correspondence between the optical characteristic and projection angle of the light emitted, but also a time taken for the projected light to reach each photodetector since the start of sweeping are applicable. See, for example, A. Gruss, S. Tada and T. Kanade, "A VLSI Smart Sensor for Fast Range Imaging", in Proceedings of the 1992 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 349-358, July 1992.

EMBODIMENT 2

Figure **5** illustrates a configuration for a rangefinder according to a second embodiment of the present invention. In Figure **5**, the same members as those included in the prior art rangefinder shown in Figure **22** are identified by the same reference numerals and the detailed description thereof will be omitted herein. In the rangefinder shown in Figure **5**, light is also projected from a light source section **10** and part of the light that has been reflected from an object **1** is also received at a camera section **310**, thereby obtaining information about the 3D location of the object **1**. According to the sec-

ond embodiment, the camera section **310** can capture a color image (i.e., a 2D image), too. The 3D location information is obtained by the known technique.

The camera section **310** includes a lens **312**, a diaphragm **313**, an imager (CCD) **314** and a neutral density (ND) filter **311**, which is disposed in front of the lens **312**. The ND filter **311** includes a liquid crystal device. The transmittance of the ND filter **311** is controllable based on a voltage applied to the liquid crystal device. An exposure controller **301** is equivalent to the controller as defined in the appended claims. The exposure controller **301** controls the diaphragm **313** or ND filter **311** of the camera section **310** or the optical output power (emission intensity) of the light source section **10** responsive to a video signal output from the camera section **310**.

Figure **6** illustrates a relationship between the operation of the rangefinder shown in Figure **5** and the transmittance of the ND filter **311**. In the illustrated embodiment, a first interval **T1**, during which a 3D image (i.e., a range image) is captured, and a second interval **T2**, during which a color image is captured, alternate one after the other. The transmittance of the ND filter **311** is set relatively low in the first interval **T1** but relatively high in the second interval **T2** by the exposure controller **301**. In the first interval **T1**, the light source section **10** is controlled by the

exposure controller **301** and light source section controller **16** as in conventional 3D imaging. In the second interval **T2** on the other hand, the light source section **10** is turned OFF.

Figure **7** illustrates a relationship between the sensitivity of the imager **314** included in the camera section **310** and the wavelength of the incident light. The light projected from the light source section **10** has its wavelength defined in the near infrared range. The sensitivity of the imager **314** in the camera section **310** is adjusted as shown in Figure **7**. As can be seen from Figure **7**, part of the incident light in the visible range is used for capturing a color image, while another part of the incident light in the near-infrared range is used for 3D imaging, i.e., capturing a range image.

Next, the technical feature of the rangefinder according to the second embodiment will be described with reference to Figures **8(a)** and **8(b)**. Figure **8(a)** illustrates the level of the video signal in the first 3D imaging interval **T1**, while Figure **8(b)** illustrates the level of the video signal in the second 2D imaging interval **T2**.

According to this embodiment, the settings of the diaphragm **313** and ND filter **311** are switched between the first and second intervals **T1** and **T2** to realize highly precise 3D imaging without deteriorating the quality of the 2D image. Specifically, in capturing a 3D image, the signal level **LB** of the image component representing the object is set much lower

than the signal level **L2** of the color image component for 2D imaging, thereby setting the signal level **LA** of the reflected part of the light projected from the light source section **10** sufficiently high.

For example, the exposure controller **301** sets relatively high, or preferably maximizes, the transmittance of the ND filter **311** in the second interval **T2**. Also, the exposure controller **301** controls the exposure conditions of the camera section **310**, e.g., diaphragm stop, sensitivity of the imager or shutter speed, such that the color image component shows a signal level **L2**, which is high enough but does not reach the saturated level. In this case, the control may be performed in such a manner as to obtain the color image through appropriate exposure. For instance, the average pixel value should be at a predetermined reference level or more, or the peak pixel value should correspond to a maximum luminance value.

In the first interval **T1** on the other hand, the exposure controller **301** sets the transmittance of the ND filter **311** relatively low, thereby lowering the signal level **LB** of the background light, i.e., the image component of the object. And the exposure controller **301** controls the exposure conditions of the camera section **310** such that the range image shows a signal level **L1**, which is high enough but does not exceed the dynamic range of the imager in the camera section **310**. Since the transmittance of the ND filter **311** is set low

in this case, the signal level **LA** of the reflected part of the light projected from the light source section **10**, which is essentially equal to the range image component, also decreases. Accordingly, the substantial range image component **LA** should preferably be increased by setting the optical output power (emission intensity) of the light source section **10** high. As a result, a range image with a high signal-to-noise ratio can be obtained.

Furthermore, a third interval, during which the light is not emitted from the light source section **10**, may be provided at the end of the second interval **T2**. In the third interval **T3**, the transmittance of the ND filter **311** may be controlled so as to minimize the signal level of the color image component. Even so, if the optical output power of the light source section **10** is set high, then the dynamic range **L1** of the range image does not decrease in the first interval **T1**.

It should be noted that the optical output power of the light source section **10** may be increased or decreased adaptively in addition to controlling the transmittance of the ND filter **311**. In this case, the total optical output power is controlled while allowing the intensity of the light to change in a similar pattern to that illustrated in Figure **24(a)**.

Instead of controlling the transmittance of the ND filter **311**, the shutter speed of the camera section **310** may be changed (e.g., by using the electronic shuttering function of

the CCD) to control the intensity of incoming light as shown in Figure **4**. In such a case, the light source section **10** should project a patterned light beam.

In the foregoing embodiment, the transmittance of the ND filter and the exposure conditions of the camera section are both supposed to be controlled. Alternatively, either the transmittance or the exposure conditions may be controlled.

Also, the first and second intervals **T1** and **T2** are supposed to alternate in the foregoing embodiment. However, the present invention is in no way limited to such a specific embodiment, but is applicable to even a situation where one of these intervals **T1** and **T2** lasts continuously. Furthermore, the same sample rate does not have to be applied to both 2D and 3D imaging. For example, the sample rate for 3D imaging may be set longer than that for 2D imaging.

Figure **9** illustrates another exemplary arrangement of the light source and camera sections in the rangefinder according to the second embodiment. As shown in Figure **9**, the light source section **10A** may include just one light source **51**. In such a case, in the first 3D imaging interval **T1**, two types of patterned light beams may be projected on a time-sharing basis as shown in Figure **10**.

EMBODIMENT 3

Figure **11** illustrates a configuration for a videophone system including an imager according to a third exemplary em-

bodiment of the present invention. In Figure **11**, the same members as those included in the rangefinder shown in Figure **5** are identified by the same reference numerals and the detailed description thereof will be omitted herein. In this case, an object **711** is a human face.

Figure **12(a)** illustrates how the imager shown in Figure **11** performs time-sharing processing. As shown in Figure **12(a)**, first and second intervals **T1** and **T2** alternate according to this embodiment. In the first interval **T1**, an infrared flash lamp **701a** is lit and the image captured is divided into foreground and background parts based on the reflected part of the light. In the second interval **T2**, a color image (i.e., a 2D image) is captured and only the foreground part is separated from the image.

As shown in Figure **11**, a light source section **701** includes the infrared flash lamp **701a** and a transmission liquid crystal display **701b**. Following an instruction issued from a light source controller **702**, the infrared flash lamp **701a** is lit twice per first interval **T1** (at times **tA** and **tB**) to irradiate the object **711** with an infrared ray. The transmission liquid crystal display **701b** functions as a sort of filter showing a transmittance variable with the spot of the incident and outgoing light beam, and can exhibit two types of distribution patterns of transmittance. These transmittance distribution patterns are switched every time the infrared flash

lamp **701a** is lit responsive to the instruction issued from the light source controller **702**. Accordingly, the intensity patterns of the light beams projected onto the object **711** change as shown in Figure **12(b)**. In Figure **12(b)**, intensity patterns **IA** and **IB** correspond to the times **tA** and **tB**, respectively. Both of these intensity patterns **IA** and **IB** change depending on the projection angle θ.

A color signal processor **703** processes the color image captured during the second interval **T2**. A foreground distinguisher **704**, which is an exemplary foreground/background distinguisher as defined in the appended claims, divides the image into foreground and background parts in response to the output signal of the camera section **310**. In accordance with the result of division performed by the foreground distinguisher **704**, a separator **705** separates a foreground image component from the image output from the color signal processor **703**. A videophone **706** sends the foreground image that has been provided from the separator **705** and an audio signal, which has been supplied from a telephone receiver **707**, out to a person at the other end of a telephone line **708**. A controller **709** controls the ND filter **311**, diaphragm **313** and light source controller **702** in the same way as the exposure controller **301** according to the second embodiment. In addition, the controller **709** also controls the color signal processor **703** and foreground distinguisher **704** in terms of the

processing timing, for example.

Next, it will be described with reference to Figures **13(a)** through **13(d)** how the videophone system shown in Figure **11** operates. Just like Figure **12(b)**, Figure **13(a)** also shows the intensity patterns **IA** and **IB** of the light projected on the object **711**. Figure **13(b)** illustrates a relationship between an intensity ratio **IA/IB** and a projection angle θ. As can be seen from Figure **13(b)**, there is one-to-one correspondence between the intensity ratio **IA/IB** and the projection angle θ. That is to say, if the intensity ratio **IA/IB** is known, then a corresponding projection angle θ is identifiable immediately.

In the first interval **T1**, the imager **314** of the camera section **310** twice receives the reflected part of the infrared ray that has been emitted from the infrared flash lamp **701a**. Responsive to the video signal provided from the imager **314**, the foreground distinguisher **704** obtains the intensity ratio **IA0/IB0** for each pixel. Then, as shown in Figure **13(c)**, the foreground distinguisher **704** determines based on the intensity ratio **IA0/IB0** whether each pixel belongs to the foreground or background. Specifically, if the intensity ratio **IA0/IB0** obtained is found greater than a predetermined reference value R_{TH}, then the foreground distinguisher **704** regards the associated pixel as belonging to the foreground (i.e., the human face in this case). Alternatively, if the ratio

IAO/IBO obtained is found smaller than the reference value R_{TH}, then the foreground distinguisher **704** regards the associated pixel as belonging to the background. The foreground distinguisher **704** performs such decision for all the pixels, and supplies the results to the separator **705**.

Hereinafter, it will be briefly described with reference to Figure **13(d)** why such level determination is possible.

In a videophone system such as that illustrated in Figure **11**, the center **P** of the object **711** in front of the camera section **310** can be predefined at an average location. Thus, a projection angle θ_{TH} corresponding to the center **P** that has been predefined in this manner can be regarded as reference angle. As can be seen from Figure **11**, if the projection angle is greater than the reference angle θ_{TH}, then the object **711** is located closer to this system than the center **P** is. Alternatively, if the projection angle is smaller than the reference angle θ_{TH}, then the object **711** is located more distant from this system than the center **P** is. There is one-to-one correspondence between the projection angle and the intensity ratio as described above. Thus, by using, as a reference, the intensity ratio R_{TH} associated with the reference angle θ_{TH}, the foreground/background division can be performed directly based on the intensity ratio obtained.

Next, in the second interval **T2**, the camera section **310** captures a color image of the object **711**. The color signal

processor **703** receives the video signal from the camera section **310**, processes the signal in a predetermined manner and then outputs a color video signal to the separator **705**. Based on the results of division performed by the foreground distinguisher **704**, the separator **705** separates only the foreground part from the color video signal output from the color signal processor **703**, and then passes the foreground part separated to the videophone **706**. The videophone **706** outputs the foreground image and the audio signal, which has been supplied from the telephone receiver **707**, over the telephone line **708**.

It should be noted that the reference value R_{TH} may be represented by a hysteresis loop as shown in Figures **14(a)** and **14(b)**. Then, the foreground/background division can be performed even more precisely even if noise is superimposed.

In the foregoing embodiment, the foreground/background division is carried out based on an intensity ratio obtained. Alternatively, the division may be performed based on the emission intensity itself. In such a case, the foreground/background division can be performed directly based on the intensity **IB**, i.e., the intensity of the light beam that was projected at the time **t2** (or **t1**) and then received at the imager **314**, with respect to a predefined reference intensity I_{TH} as shown in Figure **15(a)**. This is because there is also one-to-one correspondence between the projection angle θ and

the emission intensity as shown in Figure **15(b)**. However, unlike the case of using the intensity ratio, the emission intensity itself differs depending on the color of the object **711** at the surface. Accordingly, to perform the foreground/background division as precisely as the case of using the intensity ratio, the reference intensity I_{TH} should be changed depending on the surface color of the object **711**.

In the foregoing embodiment, the infrared flash lamp **701a** is adopted as an exemplary light source. Alternatively, a lamp of the type emitting light continuously may also be used. In such a case, the camera section **10** should be provided with an imager for capturing only visible light and another imager for capturing only the infrared radiation. Also, as shown in Figure **24**, the object may be swept with the projected radiation by modulating the emission intensity with time.

It is naturally possible to separate the background part, in place of the foreground one, from the image in a similar manner.

Modified Example 1

Figure **16** illustrates an exemplary configuration for a videophone system according to a first modified example of the third embodiment. In Figure **16**, the same members as those illustrated in Figure **11** are identified by the same reference numerals. The system shown in Figure **16** is different from the counterpart shown in Figure **11** in that the system shown in

Figure **16** additionally includes a threshold determiner **1201** for determining a threshold value as a reference of foreground/background division for each individual object. Based on the distribution of intensities of reflected light beams associated respective pixels, the threshold determiner **1201** determines the threshold value. More specifically, the threshold determiner **1201** determines the threshold value by mode method, P-tile method or Ohtsu's criterion decision method in response to the output signal of the camera section **310**.

Figure **17(a)** illustrates how to determine the threshold value by the mode method. According to the mode method, the distribution of intensities of reflected light beams associated with respective pixels is represented as a histogram and a value at the bottom of the histogram is regarded as the threshold value. Suppose the histogram shown in Figure **17(a)** is obtained based on the luminance ratios of respective pixels that are output from the imager **314** (i.e., the intensity ratio shown in Figure **13(b)**). The threshold determiner **1201** identifies the bottom of the histogram and determines the intensity ratio $\mathbf{R_{TH}}$ at the bottom as the threshold value. Accordingly, a different threshold value is obtained for each individual object, thus realizing even more precise foreground/background division. The threshold value that has been determined by the threshold determiner **1201** is provided to the foreground distinguisher **704**.

Alternatively, the distribution of emission intensities themselves may also be used instead of the intensity ratio. In such a case, the reference intensity I_{TH} shown in Figure **15(a)** is determined. As described above, if the intensity itself is used as a reference of foreground/background division, then the result of such a division is much more likely to be affected by the color of the object **711**. Thus, the threshold determiner **1201** can greatly contribute to the improvement of division precision.

Figure **17(b)** illustrates how to determine the threshold value by the P-tile method. According to the P-tile method, when a cumulative value reaches a predetermined value in a cumulative histogram, the predetermined value is regarded as the threshold value. Suppose the cumulative histogram shown in Figure **17(b)** is obtained based on the intensity ratios of respective pixels that are output from the imager **314**. The threshold determiner **1201** regards an intensity ratio R_{TH}, which is associated with a cumulative frequency of P%, as the threshold value. In a videophone system, the foreground part (i.e., a human face) would normally account for a substantially constant percentage of the whole picture captured by the camera. Accordingly, the P value of the cumulative frequency may be predefined as well.

According to the Ohtsu's method, the threshold value is determined so as to maximize an inter-class variance between

two separate regions around the threshold value. The total area of the image captured by the camera is divided into two regions **R1** and **R2**. The inter-class variance $\sigma_B^2(t)$ is given by the following Equation (2):

$$\sigma_B^2(t) = \omega_1(\mu_1 - \mu_T)^2 + \omega_2(\mu_2 - \mu_T)^2 = \omega_1 \cdot \omega_2(\mu_1 - \mu_2)^2 \qquad (2)$$

where ω_1 and ω_2 are ratios of the regions **R1** and **R2** to the entire area (i.e., $\omega_1 + \omega_2 = 1$), μ_T is an average brightness value over the entire area, σ_T^2 is variance and μ_1 and μ_2 are average brightness values of the regions **R1** and **R2**, respectively.

The decision criterion $\eta(t)$ is given by the following Equation (3):

$$\eta(t) = \sigma_B^2(t) / \sigma_T^2 \qquad (3)$$

A value of t associated with the maximum value of $\eta(t)$ is obtained as the threshold value.

The foregoing three methods are adopted just as illustrative digitizing techniques. Thus, it is naturally possible to obtain the threshold value by any other digitizing technique.

Modified Example 2

Figure **18** illustrates an exemplary configuration for a videophone system according to a second modified example of the third embodiment. As in Figure **16**, the same members as those illustrated in Figure **11** are identified by the same reference numerals in Figure **18**. The system shown in Figure **18** is different from the counterpart shown in Figure **11** in that

the system shown in Figure **18** additionally includes a distance-measuring sensor **1401** such as ultrasonic sensor. A threshold determiner **1402** determines a threshold value for each individual object **711** based on not only the signal output from the imager **314** but also on the range information provided from the distance-measuring sensor **1401**.

Specifically, the threshold determiner **1402** obtains a surface reflectance **R** of the object **711** based on the output signal of the imager **314** and the distance to the object **711** that has been measured by the distance-measuring sensor **1401**. Then, based on the surface reflectance **R**, the threshold determiner **1402** determines the threshold value as a reference of foreground/background division.

Hereinafter, it will be described in more detail how to determine the threshold value.

The distance-measuring sensor **1401** detects an approximate distance **r** to the object **711** and outputs the value **r** to the threshold determiner **1402**. Based on the approximate distance value **r** and the intensity **IB** (or **IA**), which is the output of the imager **314**, the threshold determiner **1402** estimates the surface reflectance **R** of the object **711** for each pixel by the following Equation (4):

$$R = I_B \cdot r^2 / (K \cdot A) \qquad (4)$$

where K is the brightness of the light source and A is the sensitivity of the imager **314**.

And based on the surface reflectance **R** obtained, the threshold determiner **1402** determines the threshold value of the intensity **IB**, i.e., the reference intensity I_{TH} shown in Figure **15**. First, the threshold determiner **1402** determines a threshold value IW_{TH} associated with a white foreground (i.e., the surface of the object **711**). This threshold value IW_{TH} is determined to obtain an optimum separate image by getting the threshold value adjusted by an operator while watching a monitor screen (not shown). This threshold value is determined either as an initialization step when this system is designed or fabricated or as a calibration needed before this system is operated for the first time.

By modifying Equation (4) and using the white surface reflectance R_W as a reference, the reference intensity IW_{TH} associated with the white foreground is given by the following Equation (5):

$$IW_{TH}=R_W \cdot S \tag{5}$$

where $S=K \cdot A/r^2$.

Accordingly, the reference intensity I_{TH} for an arbitrary surface reflectance **R** of the foreground is given by the following Equation (6) using the predetermined reference intensity IW_{TH} and the white surface reflectance R_W:

$$I_{TH}=IW_{TH}(R/R_W) \tag{6}$$

In this manner, the surface reflectance **R** can be obtained by Equation (4) and the reference intensity I_{TH} can be obtained by

Equation (6) for each individual object **711**.

When the intensity itself is used as a reference of foreground/background division, the result of such a division is much more likely to be affected by the color of the object **711** as described above. Thus, the threshold determiner **1402** can greatly contribute to the improvement of division precision.

In the foregoing embodiment, the distance-measuring sensor **1401** is provided as exemplary means for providing range information to the threshold determiner **1402**. Alternatively, the range calculator **30** shown in Figure **5** may be provided instead of the distance-measuring sensor **1401**. In such a case, the range calculator **30** may obtain an average distance to the object **711** around at its center and output the average as the approximate distance **r** to the threshold determiner **1402**.

Figure **19** illustrates another exemplary arrangement for the light source section **701**. In the example illustrated in Figure **19**, two infrared LED arrays **1501a** and **1501b** are vertically disposed such that the projected light beams thereof are directed toward the object **711**. And two filters **1502a** and **1502b** with adjustable transmittance are placed in front of the LED arrays **1501a** and **1501b**, respectively. The transmittance values of the filters **1502a** and **1502b** are adjusted such that the intensities **IA** and **IB** of the light beams that have passed through these filters **1502a** and **1502b** change depending on the location as shown in Figure **13(a)**.

Also, the threshold value used as a reference of foreground/background division may be changed depending on the pixel location in the imager as shown in Figure **20**. In this manner, the displacement of the object as viewed from each pixel in the imager can be corrected. As a result, the foreground/background division can be performed even more precisely.

Furthermore, the threshold value R_{TH} may be determined as shown in Figure **21** such that a relationship between an inverse $1/R_{TH}$ of the threshold value R_{TH} and $1/\Phi$, which is an inverse of the horizontal pixel location, is given by the following Equation (7):

$$1/R_{TH} = k1 \cdot \Phi + k2 \qquad (7)$$

where k1 and k2 are predetermined constants.

This equation approximates a threshold value R_{TH} that has been determined depending on the depth of the object **711** when the viewing angles ϕ and θ of the camera section **310** and the light source section **710** at the object **711** are small as shown in Figure **11**. Alternatively, an inverse of the angle ϕ may be used as Φ. The foregoing Equation (7) uses a linear function. Instead, any other monotonically changing function may be used.